Assistive Technology and Learning Disabilities: Today's Realities and Tomorrow's Promises

Rena B. Lewis

Abstract

Many forms of technology, both "high" and "low," can help individuals with learning disabilities capitalize on their strengths and bypass, or compensate for, their disabilities. This article surveys the current status of assistive technology for this population and reflects on future promises and potential problems. In addition, a model is presented for conceptualizing assistive technology in terms of the types of barriers it helps persons with disabilities to surmount. Several current technologies are described and the research supporting their effectiveness reviewed: word processing, computer-based instruction in reading and other academic areas, interactive videodisc interventions for math, and technologies for daily life. In conclusion, three themes related to the future success of assistive technology applications are discussed: equity of access to technology; ease of technology use; and emergent technologies, such as virtual reality.

Assistive technology can be broadly conceptualized as any technology with the potential to enhance the performance of persons with disabilities. As defined by the Individuals with Disabilities Education Act Amendments of 1997, assistive technology is "any item, piece of equipment, or product system . . . that is used to increase, maintain, or improve functional capabilities of individuals with disabilities" [Part A, Sec. 602 (1)]. Assistive technology offers a wide range of alternatives. It includes both "low" technologies and "high"-tech devices, and it incorporates technologies designed specifically for people with disabilities as well as generic technologies developed for use by the general public.

It is a mistake to think too narrowly about assistive technology; the entire technology spectrum holds promise for individuals with learning disabilities (LD). Although computers are the technology most often associated with this population, there are many other potentially valuable tools available. For example, long before the arrival of computers in classrooms, teachers used simple, low-tech devices such as rulers to help students with learning disabilities keep their place while reading. Off-the-shelf technologies designed for general audiences also merit consideration. For example, an audiotape recorder becomes an assistive technology when it is used by a person with learning disabilities to compensate for memory problems. In addition, technologies designed for other groups of persons with disabilities should not be ignored (e.g., technologies that help persons with vision impairments to circumvent the barriers imposed by print).

Assistive technology has a long history—perhaps even as long as that of humankind. Consider this example offered by an adapted equipment specialist for the United Cerebral Palsy Association (cited in Scherer, 1993):

> We all use adapted equipment. Take for example the pencil I'm holding. It allows ideas in my brain to be recorded on paper. But millions and millions of people cannot use this pencil; generally they're in the first grade. So what do we do? We make larger pencils for them that they can hold. We give them a piece of adapted equipment. (p. 20)

Today, the use of assistive technology by persons with learning disabilities is a common and accepted practice. However, such widespread use is a relatively recent phenomenon, and one index of this is the availability of computers for classroom use. In the early 1980s, less than half of U.S. public schools owned a computer (Quality Education Data, 1985). By the late 1980s, almost every school owned at least 1 (Office of Technology Assessment, 1988; Scrogan, 1988), and by the early 1990s, the number of computers had risen to 2.5 million, or approximately 1 computer for every 19 students (Market Data Retrieval, cited in Kinnaman, 1992).

As technologies such as computers were increasing in number, the nature of these technologies was also changing in several ways. First, technology has become more powerful in the last decade and, at the same time,

cheaper. For example, the memory capacities of computers sold today are measured in megabytes, not the kilobytes of a decade ago, and their costs (like those of other technologies, such as VCRs) have steadily decreased over time. Second, a variety of new technologies have become available, including fax machines, cellular phones, CD players, personal digital assistants, and voice-input devices for computers. Third, there has been a dramatic increase in the quality of technology, particularly in relationship to computer software. Today's software, with its realistic sound, dazzling visuals, and on-screen videos, bears little resemblance to the software of a decade ago, when green text in all capital letters was sometimes alleviated by blocky graphics.

At present, there is general agreement that computers and other technologies have great potential for enhancing the capabilities of children, youth, and adults with learning disabilities (Alliance for Technology Access, 1994; Lewis, 1993; Lindsey, 1993; Male, 1994). This article explores that potential in three ways: from a theoretical point of view, in relation to the current status of assistive technology for persons with learning disabilities, and from a futuristic perspective.

A Model for Conceptualizing Assistive Technology

According to Lewis (1993), assistive technology has two major purposes. First, it can augment an individual's strengths so that his or her abilities counterbalance the effects of any disabilities. Second, technology can provide an alternate mode of performing a task so that disabilities are compensated for or bypassed entirely. For instance, individuals with difficulties in reading may be able to capitalize on good listening skills and listen to books on tape, rather than reading the print versions. Persons with poor computational skills might use a handheld calculator; those with poor spelling might write with a word processor that offers spelling assistance. Cavalier, Ferretti, and Okolo (1994) suggested a similar distinction. According to these authors, technology can act as a cognitive prosthesis, replacing an ability that is missing or impaired, or as a cognitive scaffold, providing the support needed to accomplish a task.

Disabilities can impose barriers to full participation in school, at work, and in other important areas of life. Assistive technology offers ways to surmount those barriers. As the following sections explain, one way to think about the many technologies that are currently available is in relation to the type of barrier each addresses.

Print Barriers

Print materials are an obstacle to persons with vision impairments and to others who have difficulty reading. This includes preschool children, beginning readers, and individuals with learning disabilities who have not yet mastered the skill of reading. The most common way that assistive technology attempts to overcome the print barrier is to present information through a sense other than vision. Thus, individuals who are blind might use the sense of touch to read Braille, or might gain information by listening rather than reading. For individuals with learning disabilities (and others not yet competent in reading), an auditory display of information is often more accessible than a print display. Taped books, devices that read print books aloud, and "talking" computer programs are all options.

Communication Barriers

Individuals with speech and language disorders experience difficulty with oral communication. Beginning writers and many persons with learning disabilities experience a similar difficulty with written communication. Common written communication problems related to learning disabilities are poor handwriting, spelling, organizational skills, productivity, and quality of writing (Lerner, 1993; Newcomer & Barenbaum, 1991). The most typical response to these problems is an instructional intervention. In addition, assistive technology can support individuals with learning disabilities in the writing process by providing strategies to bypass or compensate for specific problem areas. Most technological approaches to writing are computer based; examples are word processing programs, spelling and grammar aids for editing assistance, and programs to help writers organize their thoughts in the planning stage of the writing process.

Learning Barriers

Learning disabilities interfere with the learning process by inhibiting the acquisition of new skills and knowledge and the recall of previously learned material. As with communication barriers, the most typical response to problems in learning is instruction. Assistive technology plays a role by enhancing the range of instructional options available to teachers, or to adults with learning disabilities who are directing their own learning. Technology provides a wealth of alternatives to supplement or supplant traditional approaches, such as lectures and textbook readings. For example, learners can gain new information by listening to audiotapes, audio CDs, and radio; watching films, videos, and television; participating in instructional activities delivered by computer and videodisc; and interacting with electronic information sources, such as CD-ROM–based reference "books" and the data-bases found on the Internet. Computer-based instruction is one of the most popular technological alternatives; well-designed computer programs offer learners carefully sequenced, individualized activities and frequent, informative feedback on the quality of their responses. Such programs have the potential to increase the quantity, and in some cases the quality, of instruction.

Other Types of Barriers

Individuals with hearing impairments experience barriers to listening; people with physical impairments are faced with mobility barriers. Although such problems do not characterize individuals with learning disabilities, it is important to recognize that the technologies devised to circumvent one type of barrier may prove useful for another. For example, captioned films and videos designed for persons who are deaf bypass the need for intact hearing by adding text to the visual display. This text, along with its auditory counterpart, could also be used to enhance the reading skills of persons with adequate hearing (Layton, 1991). Also, there are a number of technologies that help persons with physical impairments bypass the motor demands of typing on a computer keyboard. For persons with learning disabilities, these technologies have potential for bypassing spelling demands. With voice-input devices, for example, the writer enters text in a word processor by speaking words into a microphone, rather than by typing them letter by letter.

The Current Status of Assistive Technology for Individuals with LD

At present, the most typical applications of assistive technology for individuals with learning disabilities seem to be those that are computer based. In addition, most applications incorporate hardware and software targeted at general audiences, rather than products designed specifically for persons with learning disabilities. For example, in one set of studies in which special education teachers identified the software they had found most valuable for the students with learning disabilities they served (Lewis, 1997; Lewis, Harrison, Lynch, & Saba, 1994), almost all of the top-rated programs were aimed at students in general education, not students with special needs. However, all were well-designed programs with sufficient flexibility to accommodate the instructional needs of a range of learners.

The adoption of generic hardware and software for individuals with learning disabilities makes sense for three reasons. First, there are few products available that were developed specifically for this population. Among the more than 10,000 instructional software programs now on the market (U.S. Congress, Office of Technology Assessment, 1988), it is safe to say that not more than a handful are programs especially designed to meet the needs of individuals with learning disabilities. Second, the limitations imposed by learning disabilities are also experienced by many in the general population, although to a less marked degree. All people are beginning readers and writers at some time in their life; almost everyone welcomes the assistance that calculators and spelling checkers provide. Thus, well-designed generic technologies often address the barriers that individuals with learning disabilities must confront. Third, individuals with learning disabilities are (and always have been), for the most part, a mainstreamed population. Recent data from the U.S. Department of Education (1996) indicate that more than 80% of students with learning disabilities spend all or part of the school day in general education classrooms; more than 99% are educated on general school campuses and fewer than 1% in separate environments. Given this degree of inclusion, it should not be surprising that individuals with learning disabilities are able to benefit from much of the same hardware and software as their peers in the general population.

Because difficulty with literacy skills is a hallmark of learning disabilities, reading and writing are the most typical targets of technological interventions for persons with this disability. These interventions focus on the use of word processing programs to support and enhance writing skills, and on computer-based instruction in reading. Although literacy is the predominant concern, technology is also used to address problems in other academic areas. In addition, there is an array of high- and low-tech strategies that provide compensatory support to individuals with learning disabilities as they attempt daily life tasks.

Word Processing

Word processing programs allow writers to enter text, change it with ease, store it for later use, and print any number of legible copies. Desktop publishing programs, one type of word processor, offer the same flexibility with text and add capabilities for manipulating graphics and page layout. One of the most important advantages of word processing for individuals with learning disabilities is the ease with which text can be altered. The consequences of making a spelling or grammatical error are much less disastrous when mistakes can be easily corrected, and content revisions are much more likely to occur when the writer can insert or delete text without having to rewrite the entire document. Word processing also circumvents the problems of poor handwriting, because final drafts are printed and thus legible. Word processors are available for writers of all ages, and several contain features that can assist individuals with learning disabilities in the writing process. Other alternatives include add-on programs, designed for use in conjunction with word processors, and hardware solutions, such as alternative keyboards and voice-input devices.

Speech. Some word processors "talk": At the writer's request, the program reads text aloud. The writer may choose to hear individual letters, words, sentences, paragraphs, or an entire document. Talking word processors use synthesized speech, a type of computer-based speech that is produced by matching the letters in a word to a preprogrammed set of pro-

nunciation rules. Although synthesized speech is less realistic than prerecorded digital speech, it gives writers the freedom to enter any word in their documents. With digitized speech, only words that have been prerecorded are available. Talking word processors are quite common; examples are Write:OutLoud (1992), IntelliTalk (1992), Kid Works 2 (1992), and The Amazing Writing Machine (1994). In addition, some utility programs add synthesized speech to any application, including word processors. One example is SmartVoice (1994) for Macintosh computers.

Talking word processors enable writers to monitor the accuracy of their work. Writers can elect to listen to text as it is entered, or later, in the revision stage. Discrepancies between what they intended to write and what they hear alert writers to the need for changes. Speech also may be available within program features, such as spelling checkers. Here, speech helps writers decode unknown words.

Editing Aids. Spelling checkers, grammar checkers, and thesauruses may be stand-alone programs or included as features within a word processor. Spelling checkers match the words in a document to a built-in dictionary; words not found in the dictionary are identified as misspelled and alternatives are suggested. Those alternatives typically begin with the same letter as the misspelled word and closely resemble it in spelling (e.g., *receive* and *recede* as alternatives for *receve*). Spelling checkers are not always helpful, particularly with the phonetic and idiosyncratic spellings that individuals with learning disabilities often produce. In some cases, a spelling checker is unable to offer an alternative; in others, the list of suggested alternatives does not contain the word the writer intended; in still others, the writer is unable to read the list of suggestions. Grammar checkers monitor sentences for grammatical errors and stylistic features, such as use of clichés and passive verbs. Thesauruses help writers locate synonyms (and sometimes antonyms) for words in their documents.

It is rare to see all three types of editing tools in one word processing program. The Writing Center (1991), one of the most popular desktop publishing programs for K–12 audiences, contains a spelling checker and (in the school version of the program) a thesaurus. Write:OutLoud (1992) offers a spelling checker that talks. Write This Way (1992), one of the few word processors developed specially for persons with learning disabilities (Haapa & Lewis, 1992a, 1992b), provides a talking spelling checker as well as a talking grammar checker. Microsoft Word (1992), a professional-level word processor, includes spelling and grammar checkers and a thesaurus.

Planning Aids. A number of programs assist writers in the planning stages of the writing process. Although these are often stand-alone programs, most allow writers to export the plans they have made to a word processor. One example is Inspiration (1994). With this program, the writer brainstorms ideas and arranges them in some sort of visual display, such as an idea map, cluster, story board, or flow chart. If the writer wishes, the program automatically transforms the visual display to a standard outline. Programs such as this facilitate planning and organization for persons who prefer visual depictions of the relationships among ideas.

Strategies for Text Entry. The standard computer keyboard is a barrier to writers unfamiliar with its QWERTY layout. One solution to this problem is to teach writers keyboarding skills, and there is a plentiful supply of computer software for this purpose. Examples include children's programs, such as Kid's Typing (1993), and those for all ages, such as Typing Tutor 6 (1994) and Mavis Beacon Teaches Typing (1992). Another option is to replace the standard keyboard with one arranged in a more familiar configuration. Muppet Learning Keys (from Sunburst/Wings for Learning), an alternative keyboard for young children, displays letters in alphabetical order; IntelliKeys (from IntelliTools) is a programmable alternative keyboard that can be configured to present letters in alphabetical order or in any other arrangement.

Two technologies developed for persons with physical impairments also deserve consideration. The first is voice input. A voice-input device is connected to the computer and the writer speaks, rather than typing, text. Examples are DragonDictate (from Dragon Systems, Inc.) for IBM computers and PowerSecretary (from Articulate Systems) for the Macintosh. However, although the cost of these systems has decreased markedly in recent years, it still remains high. Also, the systems must be trained to recognize the user's voice so that spoken words are equated with their written counterparts. Word prediction programs are another alternative. Designed to reduce the number of keystrokes required to enter text, these programs attempt to predict the word the writer wishes to type from the first one or two letters entered. For example, if the writer wants to begin a sentence with the word *The*, the letter *t* is typed and the program predicts alternatives, such as *The*, *That*, *They*, *To*, and *There*. Predictions are based on built-in dictionaries, grammar rules, and word frequency data. In addition, many word prediction programs collect the nondictionary words that writers use (e.g., proper nouns) so that these too can be predicted. Co:Writer (1992–94) is an example of a talking word prediction program.

Research on Word Processing. Research has been conducted with both general and special education populations to determine the effects of word processing on writing performance. In general education, results indicate small, positive effects for word processing on some, but not all, measures (Bangert-Drowns, 1993; Cochran-

Smith, Paris, & Kahn, 1991; Hawisher, 1989; Russell, 1991). In a meta-analysis of 32 studies comparing word processing with traditional writing methods, Bangert-Drowns reported that word processing positively affected writing quality, particularly for students with poor writing skills who received remedial writing instruction.

The research literature on word processing for individuals with learning disabilities is more limited, although studies of both college students and K–12 students are available. Much of the research with college students comes from the 1985–1988 Learning Disabled College Writers Project at the University of Minnesota (Collins, 1989; Collins, Engen-Wedin, Margolis, & Price, 1987; Collins & Price, 1986). In K–12, the research base includes reports of multiyear projects, such as The Computers and Writing Instruction Project (CWIP; e.g., MacArthur & Schwartz, 1990) and The Writing Project (Morocco et al., 1985; Morocco, Neuman, Cushman, Packard, & Neale, 1987; Neuman et al., 1985).

What is remarkable about this literature is the relative scarcity of studies that attempt to isolate the effects of word processing on writing performance. Instead, word processing is often combined with other interventions, most notably writing-as-a-process and instruction in strategies for writing (Kerchner & Kistinger, 1984; MacArthur & Schwartz, 1990; MacArthur, Schwartz, & Graham, 1991; Morocco et al., 1985; Stoddard & MacArthur, 1993). Combining treatments leads to the confounding of variables. As MacArthur and Schwartz observed, "the noted differences may be due primarily to the increased focus on writing" (p. 41).

Despite this, it is possible to reach some tentative conclusions about the effectiveness of word processing for individuals with learning disabilities. There is evidence to suggest that word processing leads to positive changes in writing quality, particularly when word processing is combined with instructional approaches, such as writing-as-a-process and strategy instruction (Graham & MacArthur, 1988; Kerchner & Kistinger, 1984; MacArthur & Schwartz, 1990; Yau, Ziegler, & Siegel, 1990). In addition, word processing seems to lead to increases in the quantity of text written (Graham & MacArthur, 1988; MacArthur & Schwartz, 1990; Outhred, 1987, 1989; Yau et al., 1990) and increased accuracy in conventions of written language, such as spelling and grammar (Fais & Wanderman, 1987; MacArthur & Schwartz, 1990; Outhred, 1987, 1989). However, it is important to point out that these findings are not universal. In the Yau et al. study, for example, quality and quantity improved, but accuracy in spelling and punctuation did not. In MacArthur and Graham's (1987) comparison of handwritten versus word processed texts, no differences were found in quality, quantity, or mechanical errors, although word processing was significantly slower than handwriting.

A small number of studies have investigated the effectiveness of keyboarding instruction for individuals with learning disabilities and the use of word processing features, such as speech and editing tools. Okolo, Hinsey, and Yousefian (1990) reported that keyboarding instruction improved the text-entry speed of students with learning disabilities. Spelling checkers seem to improve spelling performance (Dalton, Winburg, & Morocco, 1990; Haapa & Lewis, 1992b). Borgh and Dickson (1992) investigated the effects of speech synthesis on the writing performance of elementary-grade general education students and found that students wrote longer stories, made more editorial changes, and showed more positive attitudes to writing in the synthesis condition. However, in a preliminary report of research with college students with learning disabilities, Raskind and Higgins (1993) suggested that speech synthesis either facilitated or impeded the writing process, depending on the characteristics of individual students.

Computer-Based Reading Instruction

Although poor reading skills are typically the main academic concern with individuals with learning disabilities, technology-based interventions for reading lag far behind those for enhancing writing skills. In the 1980s, instructional software for reading presented many of the same barriers as traditional reading materials. Most programs were designed to offer drill-and-practice opportunities to help students *improve* their reading skills; to profit from them, students had to have some competency in reading. In effect, the text on the computer screen became a print barrier as formidable as the printed page. A small collection of software incorporated speech synthesis in an attempt to alleviate this problem. However, the robotic speech of early synthesizers produced sounds that were difficult to discriminate for some listeners with disabilities (Helsel-Dewert & Van Der Meiracker, 1987; Massey, 1988; Smith, Siders, & Oshrin, 1987).

In the past few years, there have been several major changes in the characteristics of instructional software for reading. These changes have occurred as a result of two forces: technical advances in software design and storage, and a paradigm shift in reading instruction toward the whole language model.

Technical Advances. In traditional software, the program directs the flow of movement from one activity to the next. Although the user may be able to make some choices about which activity to pursue, once that activity is selected, the program determines what happens first, second, and so on. The program proceeds in a linear fashion, without offering alternatives to the user. Hypertext and hypermedia software is quite different. It is designed to shift control away from the program to the user so that he or she makes the decision about what happens next. In one hypermedia reading

program described by Higgins and Boone (1991), for example, the learner can select a word in the text to hear that word pronounced, view a graphic illustrating the word's meaning, or see a structural analysis of the word. Hypertext programs are text based; hypermedia programs contain graphics, sound, and other media in addition to text. These programs offer more opportunities than traditional, linear software for interactions between the learner and the text. This capacity for enhancing the quantity and quality of interactions may have particular value for individuals with learning disabilities, a group that has been described as passive learners (Torgesen, 1977).

Another technical advance that has influenced the nature of reading software is the use of CD-ROM discs, rather than floppy disks, for program storage. Although the storage capacity of floppy disks has increased over the years, it is still relatively small, especially in relation to the memory demands of software features such as high-quality visuals and digitized speech. Compact discs (CDs) for computers resemble audio CDs; they provide read-only memory (ROM) and cannot be altered. The memory capacity of a CD-ROM disc is truly impressive—one disc can hold an entire encyclopedia or the complete works of Shakespeare. More specifically, one 4.72-inch CD can store more than 560 megabytes of information, or approximately 250,000 pages of text, 15,000 color images, or 15 hours of audio information (Holzberg, 1991; Salpeter, 1988).

With the expanded storage capabilities offered by CD-ROM, multimedia software became a possibility. Multimedia programs are multisensory; in addition to text, they can contain high-quality auditory information, photos and other types of visuals, and even on-screen videos. Auditory output is particularly important for individuals with learning disabilities and others with reading difficulties. Among the types of auditory information available in multimedia are music, sound effects, and digitized speech. Digitized speech is actual speech that has been prerecorded. Multimedia programs are now quite common; some of the most outstanding examples are CD-ROM–based reference "books." For instance, Bookshelf (1994) is a one-disc program that contains a dictionary, thesaurus, encyclopedia, book of quotations, atlas, chronology, and almanac. The dictionary pronounces words aloud, and several of the reference works contain entries with color photos, animated diagrams, audio recordings, and video clips.

The Influence of Whole Language. The whole language approach to reading instruction places primary emphasis on meaning-based interactions with text; skills instruction, although not completely banished, is not a major focus (Chiang & Ford, 1990; Gersten & Dimino, 1993; Lerner, Cousin, & Richeck, 1992; Mather, 1992). In addition, the texts that readers interact with must be whole and authentic; children's literature is considered more appropriate for young readers than the materials provided by traditional basal reading series. This shift away from skills instruction and controlled reading materials spurred a dramatic change in reading software. Traditional drill programs came to be viewed as obsolete (at least in general education), and a new type of software, the "talking" storybook, appeared on the marketplace to take their place. Although a shift back to skills-based instruction is now apparent, talking storybook programs remain popular.

Talking storybooks. Typical talking storybook programs present an entire work of children's literature on a CD-ROM disc. These are multimedia programs with impressive illustrations and high-quality digitized sound for speech, music, and sound effects. They are hypermedia in that they allow readers to interact with the text and, in most cases, the visuals that accompany the text. The interactive nature of these storybooks serves two purposes: First, interactivity acts as a motivator to encourage readers to persist in the reading task, and, second, some interactive features provide assistance in reading (e.g., a reader may be able to select an unknown word in the text to hear it read aloud). The two best-known sets of talking storybook programs are the Living Books series from Brøderbund and the Discis Books series from Discis Knowledge Research Inc. Although these series share several common characteristics, they also differ in important ways. The Living Books series contains a number of storybooks for younger readers. Just Grandma and Me, the disc-based version of the book by Mercer Mayer, was the first in the series; other titles include Arthur's Teacher Trouble, The Tortoise and the Hare, The New Kid on the Block, Little Monster at School, Harry and the Haunted House, and Arthur's Birthday. Each program comes with a print version of the book as well as its CD-ROM counterpart.

At the start of a Living Books program, the reader selects the language in which he or she will see and hear the story; the most typical choices are English and Spanish. Also, the reader chooses either the "read to me" or "let me play" mode; in the latter, the reader can interact with text and graphics. When the story begins, the text on the page is read aloud and the graphics animate; in most cases, music and sound effects accompany the narration. The reader can then choose to turn to the next page or to interact with the page on the screen.

Two types of text interactions are possible: The reader can direct the program to read one word aloud, or to reread all of the text. There is a much richer array of choices with the program's graphics because almost anything shown on the screen will perform some action if selected. For example, on the first page of Arthur's Teacher Trouble (1992), Mr. Ratburn is shown standing at the door of his classroom saying good-bye to his students for the day. The reader can make both the characters in the story and

the objects on the screen animate, speak, or produce sound effects. Among the choices on this screen are Mr. Ratburn and four of his students, the bell in the hall, a trash can, a doorknob, window shades, Mr. Ratburn's clothes, and several notices on the bulletin board, including a "learn to fly" poster that turns into a paper airplane and flies away. Obviously, rich graphics such as these can motivate young readers; however, they can also serve as distractions. In reading instruction, it is important to ensure that learners attend to the text as well as the graphics.

The Discis Books series offers programs for a wider age span of learners. Examples are classics such as The Tale of Peter Rabbit and Cinderella, The Original Fairy Tale; folktales such as Paul Bunyan and Pecos Bill; contemporary works such as A Long Hard Day at the Ranch and Somebody Catch My Homework; science and nature books such as Whales and Dinosaurs; and books for older readers such as The Tell Tale Heart. There is no animation in these programs; the Discis Books place more emphasis on interactions with text than on those with graphics. However, the teacher (or parent) has a high degree of control over the types of interactions that will occur.

Like the Living Books series, the Discis Books programs can be set to begin by reading the text on the screen with accompanying music and sound effects. In addition, the format of that text can be altered to accommodate individual learners' needs; the size of text can be changed, as well as its font, style, and spacing. There are several options for structuring the interactions between the reader and individual words. When the reader selects a word, the program can read the word aloud in English and/or in Spanish, read the word syllable by syllable, and provide an explanation of the word's meaning as it is used in the context of the story. Also, selecting one of the graphics that illustrates the story can result in the appearance of a word label, the program reading the word aloud (in English and/or Spanish), and/or the program pronouncing the word syllable by syllable. Discis Books can also be customized to allow more than one type of interaction. For instance, a reader could click on a word once to hear it pronounced and click twice to hear an explanation of its meaning.

Despite the appeal of CD-ROM–based reading software, there are some caveats. First, talking storybooks rely on discovery learning. Mere exposure to text is unlikely to help students with learning disabilities become proficient readers; as Lewis and Doorlag (1995) commented, these students "will likely require explicit instruction in skills such as decoding" (p. 274). With talking storybooks, learners can choose to interact extensively with text or they can virtually ignore it and concentrate on listening to the story and interacting with its graphics. However, 10 seconds of reading followed by 10 minutes of play is not a good use of instructional time for reading. Problems such as these speak to the need for increased instructional support from teachers when students are using discovery-learning software. A second area of concern is the scarcity of high-interest, low-vocabulary software. Although this is not surprising in software designed for general education, it presents a challenge to special educators who seek programs that are appropriate for both the age level and skill level of their students.

Research on Computer-Based Reading Instruction. In a review of literature on the use of computer-based instruction (CBI) in special education, Okolo, Bahr, and Rieth (1993) concluded that "research has demonstrated that CBI can improve skills" (p. 10) in a number of areas, including word recognition and decoding. Higgins and Boone (1993) concurred but added that traditional reading software was less effective for improving comprehension. In the general education literature, computer-based approaches to reading instruction are viewed as having positive effects on achievement, particularly for students with reading problems (Darter & Phelps, 1990; Thompson, 1990; Van-Prooyen & Clouse, 1994). One notable exception is the research on IBM's Writing to Read program. Although teachers, students, and parents have expressed satisfaction with the program (Leahy, 1991), Slavin (1991) concluded from a meta-analysis that kindergarten and first-grade students showed minimal gains in reading in relation to controls.

Two areas of inquiry in the special education literature are of particular interest: speech-enhanced text and hypermedia-enhanced text. Several studies suggest that speech is a valuable addition to reading software (Hebert & Murdock, 1994; McGregor, Drossner, & Axelrod, 1990; Wise & Olson, 1994). For example, in a review of research conducted at the University of Colorado, Wise and Olson reported that adding speech to text doubles the rate of acquisition of decoding skills. Hypermedia-enhanced text also seems to improve reading performance. Positive results have been reported for low-achieving students using hypermedia basal readers (Boone & Higgins, 1993; Higgins & Boone, 1991) and for students with learning disabilities using hypermedia study guides in social studies (Higgins & Boone, 1990).

It is important to recognize that many of the newer approaches to computer-based reading instruction have not yet been subjected to systematic study. Although software such as the talking storybooks described earlier seem to contain important instructional features, such as speech and hypermedia, final judgments must be postponed until research results are available. Highly interactive software seems capable of engaging the attention of students with learning disabilities and providing support for negotiating the print barrier. However, as Swanson (1989) hypothesized, individuals with learning disabilities typically are actively inefficient, rather than passive, learners, and thus interactive programs may actually impede

their progress by encouraging them to engage in nonreading activities.

Technologies for Other Academic Areas

Computer-based instruction is also used for academic areas other than reading and writing for students with learning disabilities. The most common interventions target spelling and mathematics skills, although some work has also been done in social studies (Higgins & Boone, 1990). Traditional spelling software offers opportunities for drill and practice. In a review of the literature on spelling instruction, Gordon, Vaughn, and Schumm (1993) concluded that CBI "can enhance spelling performance and increase motivation to learn" (p. 179). Okolo et al. (1993) agreed, although they suggested that research evidence on the effectiveness of CBI in spelling is less compelling than that on word recognition, decoding, and math computation skills.

In the 1980s, more software was available for math than for any other school skill (Lewis, 1993), and the majority of programs addressed computation skills rather than problem solving. As in spelling, traditional math software is designed for drill and practice. Well-designed CBI seems to be effective in increasing students' knowledge of math facts (Woodward & Carnine, 1993). Of particular interest are programs that target automaticity (Hasselbring, Goin, & Bransford, 1988) and those that incorporate constant time delay procedures (Koscinski & Gast, 1993). However, it is unclear whether game features in math software enhance student performance. They seem to have positive effects on motivation and attitude, but drill programs without game features may be equally as or more effective in improving achievement (Christensen & Gerber, 1990; McDermott & Stegemann, 1987; Okolo, 1992; Watkins, 1989).

Another line of inquiry related to math is the use of interactive videodisc programs to facilitate the acquisition of math concepts and problem-solving skills. Woodward and Carnine (1993) reviewed a series of studies of the Mastering Fractions (1985) videodisc and concluded that it is an effective alternative to teacher-delivered instruction. Hasselbring and his colleagues at Vanderbilt University have taken a somewhat different approach by focusing on interventions to teach problem-solving skills. For example, Bottge and Hasselbring (1993) reported on the use of a videodisc program to provide instruction and practice in solving contextualized problems, that is, problems embedded in real-life contexts. Results suggested that this type of "anchored instruction" (p. 557) helped students transfer skills to new problem situations.

Technologies for Daily Life

There are a number of technologies that can help individuals with learning disabilities cope with the demands of everyday life. Many of these, such as handheld calculators, are devices used by much of the general public. For example, many new books are published in both print and audio formats; listening to books on tape is one way to circumvent reading problems. Books are also available on computer disks, and although these typically do not offer speech output, they do allow the reader to change the appearance of the text, search for specific topics, and make marginal notes. For persons with severe reading problems, reading machines designed for individuals who are blind allow auditory access to any type of printed material. These devices use optical character-recognition technology to identify letters and words, which are then pronounced by a speech synthesizer. One example is the Reading Edge Kurzweil Reader (produced by Xerox Imaging Systems). Although such devices are quite expensive, they provide universal access to print.

In the area of writing, many persons use handheld spelling devices for assistance with handwritten documents. Franklin Learning Resources produces several handheld aids with features including speech, dictionaries, and thesauruses in addition to spell checking. In the world of work, voice mail has the capacity to eliminate many of the reading and writing demands associated with routine correspondence. Instead of reading a memo, the worker can listen to a voice mail message; instead of writing a response, he or she can reply by phone.

Technology can also assist with memory and organizational tasks. Telephones can be preprogrammed with frequently called numbers to avoid the necessity of remembering them (and dialing them in the correct sequence). Names, addresses, phone numbers, important dates, and personal memoranda can be stored in small, handheld electronic organizers for ready reference. Calendar and time management programs are available for computers and for personal digital assistants. Wanderman (1994) suggested low-tech organizational aids such as sticky notes and flags and highlighter pens and tape. Wanderman also recommended digital and talking clocks and wristwatches for ease in telling time, tape recorders for note taking, and fanny packs for keeping track of personal belongings.

The Future: Promises and Potential Problems

Although an extensive forecast is not possible within the scope of this article, it is important to discuss three major themes likely to dominate future considerations in assistive technology use for individuals with learning disabilities: equity of access, ease of use, and emergent technologies. In a broad sense, each of these deals with access issues. The most powerful technology is worthless if its operation cannot be mastered; *any* technology is worthless if its potential users are denied access to it.

Equity of Access

There is some indication from the research literature that students with

learning disabilities use school computers at least as often as their general education peers (Lewis, 1997; Lewis et al., 1994). In determining equity, however, it is necessary to consider the relative needs of different populations. As in other types of equity decisions, it may be that equal access is insufficient. Individuals with disabilities may require *enhanced* access because of the barriers their disabilities impose.

Two important legislative steps have been taken toward promoting equity of access to technology for persons with learning disabilities. One is the Americans with Disabilities Act of 1990 (ADA). This law requires that reasonable accommodations be made for individuals with disabilities in the workplace. Among those accommodations are "acquisition or modification of equipment or devices" [Sec. 101(9)(b)]. Second, the Individuals with Disabilities Education Act (IDEA) (and its 1997 amendments) requires that assistive technology devices and services be provided to children and youth with disabilities if these are necessary to ensure a free, appropriate public education (Behrmann, 1994).

However, it is not yet clear how successfully these laws will be implemented. ADA exempts employers who can demonstrate that making accommodations would create an "undue hardship" on their businesses. In IDEA, assistive technology devices and services must be included in the IEP and thus must be endorsed by the school as well as the child's parents. In a time of declining fiscal resources for education, assistive technology for students with disabilities may not be a high-priority budget item for schools and districts.

Ease of Use

In the past decade, technology has become smaller, cheaper, more powerful, and easier to use, and these trends are likely to continue. Three changes in person–technology interfaces have contributed to increased ease of use. First, there has been a movement away from command-driven control of computers and other technologies; instead of entering a command, users now typically select from a menu of options. This is particularly significant for individuals with learning disabilities because of the difficulties they encounter with command-driven software (Edyburn, 1991).

Second, interfaces have become more standard, so that the skills learned in order to interact with one technology or computer program can be applied with equal success to the next. The standard interface for computers today is graphical, with pictorial representations (icons) for various computer functions. This is a fortuitous choice for persons with learning disabilities, who may derive more information from a graphic than from its printed label.

Third, technologies designed for the general population are beginning to offer a variety of input alternatives. For example, personal digital assistants, such as the Apple Newton, accept handwritten input, rather than requiring the user to enter text on a keyboard. Some of the newer computers can be operated by voice commands (although text input by voice is not yet commonly available). Touch screens are becoming more common, particularly in situations where information is disseminated to the general public. For example, a shopper in a large mall might access information about the mall's restaurants by selecting that choice from a touch screen. Input alternatives increase the range of options for interacting with technology. When one or more of the available options is consistent with a person's strengths, technology becomes more accessible.

Emergent Technologies

Virtual reality is one emergent technology that has tremendous potential for individuals with learning disabilities. In virtual reality applications, the user not only interacts with a computer-simulated environment but also experiences it in detail. As Lewis (1993) explained, "a person might put on goggles, a headset, and gloves or a body suit to experience the sights and sounds of Mars" (p. 484; see Rayl, 1991). Although special education professionals have begun to contemplate the ways in which this technology can benefit individuals with disabilities (Woodward, 1992), the potential of virtual reality has not yet been fully assessed. One of the most important characteristics of virtual reality is its capacity to provide contextualized, or anchored, instruction (Bottge & Hasselbring, 1993). Because virtual reality can mirror the complexity of real-life situations, it can be used to construct contextualized learning environments that promote skill generalization. Consider, for example, the ways in which virtual social situations could assist individuals with learning disabilities to enhance their interpersonal interaction skills.

Likewise, new networking capabilities such as the Internet and the World Wide Web have potential for increasing the access of persons with learning disabilities to tremendously rich worldwide information sources. The Internet is a web of more than 8,000 interconnecting networks, serving 5 million to 10 million people in 45 countries on 7 continents (LaQuey & Ryer, 1994). At present, however, most networks are print-dense environments that demand both reading and writing skills from their users. These barriers must be lowered—oreradicated—if individuals with learning disabilities are to become full participants in the global interchange of information and ideas.

In conclusion, the future of assistive technology for persons with learning disabilities holds much promise, but, like all futures, it is uncertain. As the future unfolds, it is imperative that the field of special education and oth-

ers concerned with the welfare of individuals with learning disabilities continue to act as strong advocates for equitable distribution of technology resources. To persons with disabilities, technology is a means of empowerment; denying them that option exacerbates their disability's effects.

ABOUT THE AUTHOR

***Rena B. Lewis**, PhD, is a professor in the Department of Special Education, San Diego State University, and a member of the faculty of the San Diego State University–Claremont Graduate University doctoral program. Among her primary research interests is the application of technology for individuals with learning disabilities. Address: Rena B. Lewis, Department of Special Education, San Diego State University, 5500 Campanile Dr., San Diego, CA 92182-1170. e-mail: rlewis@mail.sdsu.edu*

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